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Quarkonium signal extraction in ALICE

ALICE Collaboration*

Abstract

This note describes the analytical expressions of the functions commonly used to fit the invariant-mass spectra for charmonium and bottomonium analyses performed by ALICE in the dimuon-decay channel.

*See Appendix A for the list of collaboration members

1 Introduction

Most ALICE analyses of charmonium and bottomonium states, detected in the muon spectrometer through their dimuon decay, use a similar procedure for extracting the resonance signal. Quarkonium candidates are obtained combining pairs of muons with opposite charge sign and the raw yields are then extracted using fits to the dimuon invariant-mass spectrum in a given y, p_{T} and centrality interval. The fitting function usually consists of two main components, corresponding to signal and background. In order to check the stability of the results and to assess the systematic uncertainty on the signal extraction, several combinations of signal and background shapes are used, the fitting range is varied and the signal-shape parameters that cannot be left free during the fit are fixed to different values, extracted from Monte-Carlo simulations or from larger data samples. The results obtained from the various fits are then averaged to get the central value of the extracted yield while the Root Mean Square of these results is used to estimate the corresponding systematic uncertainty. The details of the procedure slightly change from analysis to analysis, depending on the quarkonia under study, on the collision system and energy, and on the available statistics, and are reported in the corresponding papers. The aim of this note is to describe the signal shapes and some of the background shapes used in these analyses.

2 Signal shapes

The signal shape is modeled by either an "extended Crystal Ball" (CB2) function, allowing non-Gaussian “tails” both on the left (low-mass) and right (high-mass) sides of the resonance peak, or a “NA60 function” (a Gaussian with a fixed-width core around the resonance pole and mass-dependent widths on the right and on the left side of it). The analytical forms of both functions are given below. In both of them x is the dimuon invariant mass.

2.1 CB2 function

Crystal Ball (CB) function was first introduced in [1]. This function consists of a Gaussian core, that models the detector resolution, with a power-law “tail” at low mass accounting for energy loss effects. The extended Crystal Ball function used in the ALICE analyses has power-law “tails” on both sides of the Gaussian core. The high-mass tail is attributed to multiple Coulomb scattering in the front absorber and momentum resolution. The CB2 function is defined as follows:

$$f(x;N,\bar{x},\sigma,t_1,t_2,p_1,p_2) = N \cdot \begin{cases} A \cdot (B-t)^{-p_1} & , t \leq t_1 \\ \exp\left(-\frac{1}{2}t^2\right) & , t_1 < t < t_2 \\ C \cdot (D+t)^{-p_2} & , t \geq t_2 \end{cases} , \tag{1}$$

where

$$\begin{aligned} t &= \tfrac{x-\bar{x}}{\sigma} \\ A &= \left(\tfrac{p_1}{|t_1|}\right)^{p_1} \cdot \exp\left(-\tfrac{|t_1|^2}{2}\right) \\ B &= \tfrac{p_1}{|t_1|} - |t_1| \\ C &= \left(\tfrac{p_2}{|t_2|}\right)^{p_2} \cdot \exp\left(-\tfrac{|t_2|^2}{2}\right) \\ D &= \tfrac{p_2}{|t_2|} - |t_2| \end{aligned}$$

The parameters A, B, C and D are defined so that both the function and its first derivative are continuous.

2.2 NA60 function

The NA60 function was first introduced for the charmonium signal extraction by the NA60 Collaboration as reported in [2]. In ALICE analyses it is defined as a function of the dimensionless parameter $t = \frac{x-\bar{x}}{\sigma}$, similarly to the formulation of the CB and CB2 functions. It is formulated as follows:

$$f(x;N,\bar{x},\sigma,t_1,t_2,p_1,...,p_6) = N \cdot \exp\left(-\frac{1}{2}\left(\frac{t}{t_0}\right)^2\right), \tag{2}$$

where

$$t = \frac{x-\bar{x}}{\sigma}$$

and

$$t_0 = \begin{cases} 1+(p_1(t_1-t))^{p_2-p_3\sqrt{t_1-t}} & , t \leq t_1 \\ 1 & , t_1 < t < t_2 \\ 1+(p_4(t-t_2))^{p_5-p_6\sqrt{t-t_2}} & , t \geq t_2 \end{cases}$$

3 Background shapes

Several ad-hoc functions are commonly used in quarkonium analyses. The main ones are described below.

3.1 Variable-Width Gaussian function

The Variable-Width Gaussian (VWG) function is defined as follows:

$$f(x;N,\bar{x},A,B) = N \cdot \exp\left(-\frac{(x-\bar{x})^2}{2\sigma_{VWG}^2}\right), \tag{3}$$

where

$$\sigma_{VWG} = A + B \cdot \frac{(x-\bar{x})}{\bar{x}}$$

3.2 Polynomial times exponential functions

A simple product of a polynomial times an exponential function is often used for the parameterization of the background, with the order of the polynomial depending on the analysis:

$$f(x;N,p_0,...p_n) = N \cdot \exp(p_0 x)\left(p_1 + p_2 x + ... + p_n x^{n-1}\right) \tag{4}$$

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